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Time-Triggered Protocol (TTP) for Integrated Modular Avionics (IMA)

Draft Version
Content to be updated for MAPLD conference presentation

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The Integrated Safety-Critical Advanced Avionics Communication & Control (ISAACC) System is the product of the Propulsion High-Impact Avionics Technologies (PHIAT) project at NASA Marshall Space Flight Center (MSFC) during FY03 to the end of FY05

- Originally funded under Next Generation Launch Technologies (NGLT) for four years beginning in mid FY03
- Tasked to develop avionics technologies for control of next generation reusable rocket engines
- Funded under the Exploration Systems Mission Directorate (ESMD) through end of FY05
- Broadened scope to include vehicle systems control for human and robotic missions

The goal is an avionics architecture suitable for control and monitoring of safety critical systems of manned spacecraft

- Scalable to allow its use in robotic vehicles or launch pad and propulsion test stand monitoring and control systems.

Four primary areas of focus for the ISAACC distributed real-time control system to provide a reliable system for human spaceflight, while also providing scalability and addressing cost sensitivity and sustaining engineering.

- Modular components
  - High reusability
  - Flexibility to accommodate upgrades
  - Limit number of unique designs
  - Scalable
- Hard real-time, safety critical communications between modules and systems of modules
  - Fault detection, containment and tolerance
  - High availability, High reliability
  - Guaranteed quality of service – low jitter/latency
- Distributed intelligence
  - Complex functionality using processing elements with moderate capability (i.e. Current Rad Hard processors/FPGAs)
  - Fault Tolerance / Fault Detection, Isolation and Recovery (FDIR)
- Plug-and-Play / Hot Swap at all levels (Modules, Transducers, Controlled Components)
  - Improved maintainability
  - Increased flexibility
  - Reduce cost of software changes / unique software configurations

Federated

- every LRU/ECU has one function only
- Power supply & rugged chassis for every LRU
- Excessive weight, higher system integration hard to accomplish

Integrated Modular Avionics (IMA)

- Common power supply & rugged chassis for a set of modules
- many upgradeable SW functions on one module (i.e. processing unit)
- Reduced weight, straightforward update and system integration
- Partitioning and MMU important!

  Note: MMU=Memory Management Unit

IMA philosophy

- Run many partitioned functions on one embedded computer
- Use shared resources (processing time, I/O, power supply, ...)

Distributed IMA philosophy

- Run many partitioned functions on one distributed fault-tolerant embedded computer
- Share common communication medium

TTP: A Distributed IMA Platform Technology

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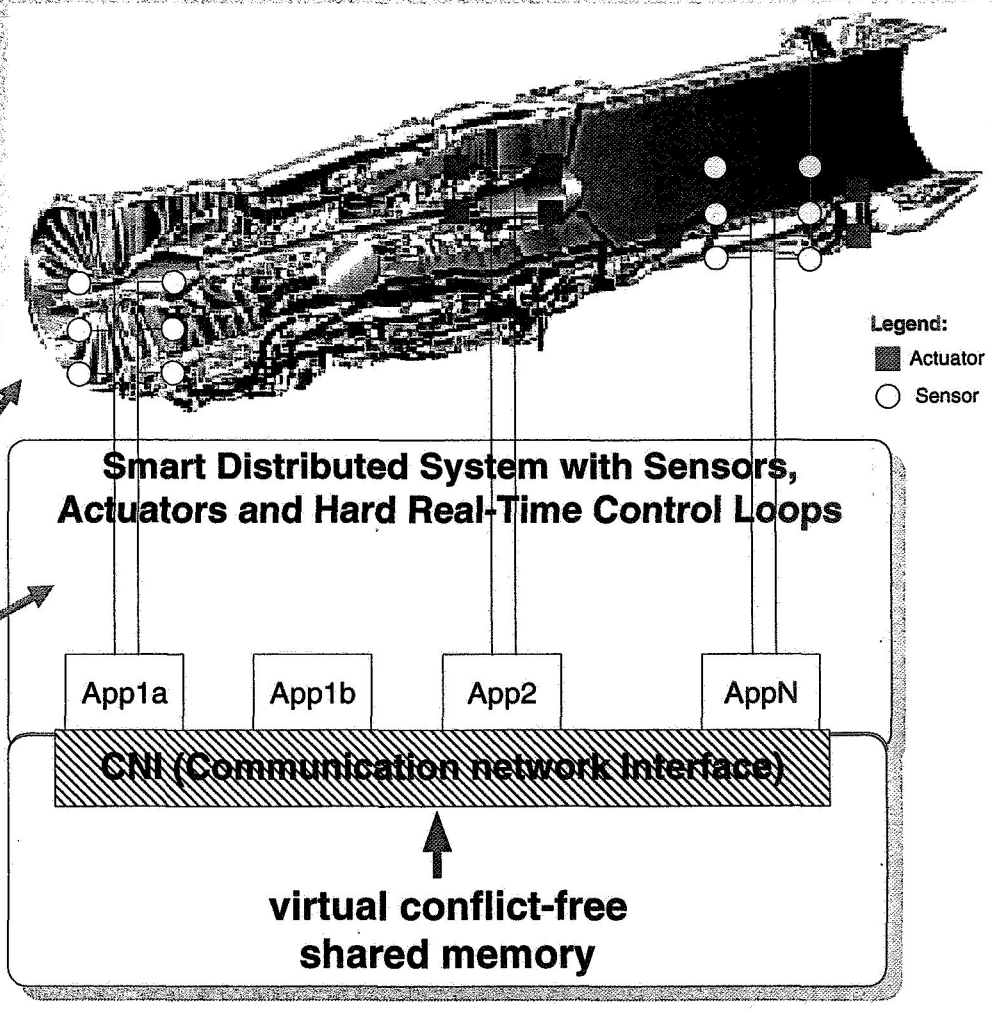
"The network is a deterministic fault-tolerant hard real-time embedded computer"

- system architecture with system redundancy and voting
- system health monitoring and high data integrity
- strictly deterministic communication (max. 25MBit/s))
- system synchronization (jitter in µs range)

Application designer focused on:

- application-specific issues
- fast real-time control loops



TTP: Built-in Distributed Services

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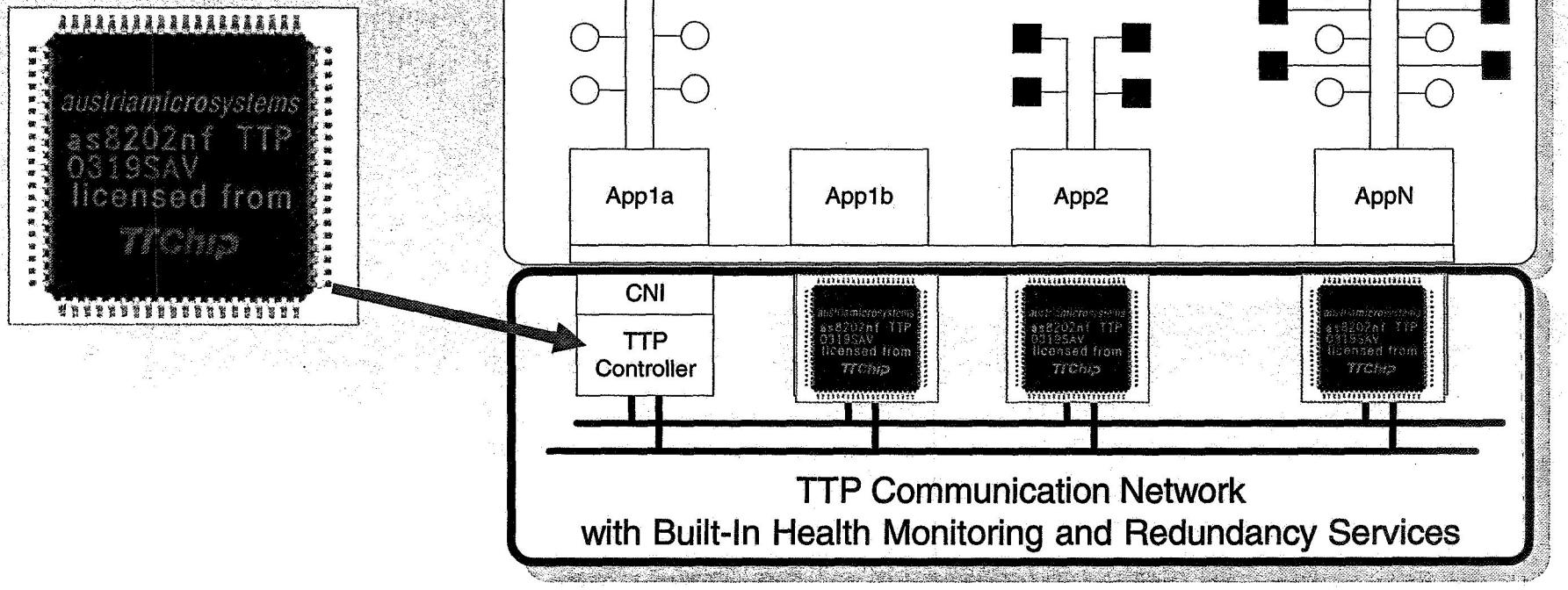

On-chip TTP protocol guarantees autonomous operation of communication system, independent of application host/software:

TTP: Parametric System Design

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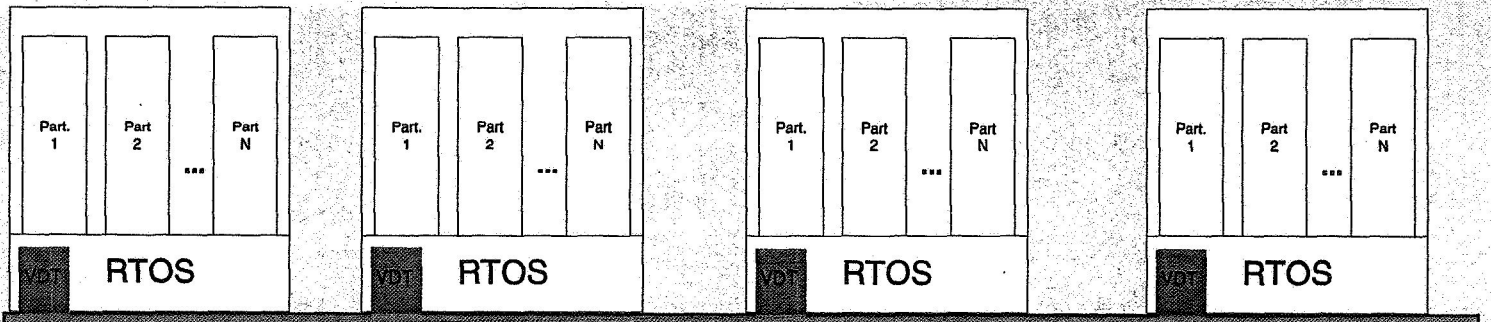
Parametric design of LRU software behavior (RTOS, def. table)

- Standard software application interfaces
- Definition of conflict-free use of shared resources
- Definition of LRUs temporal behavior



TTTech: Parametric system architecture definition (TTP; MEDL)

MEDL

- Definition and tight control of key system interfaces
- Independent of topology, physical layer or distance
- Definition of conflict-free use of system shared resources
- Definition of system temporal behavior

TTP: System (not only LRU SW!) Partitioning

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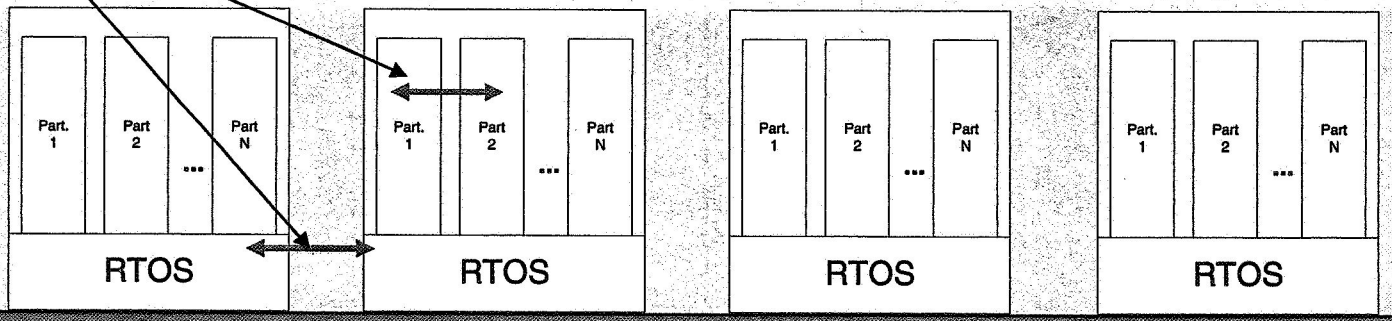
Software partitioning using MMU and scheduled resource use

- No fault propagation to other software partitions
- Conflict-free use of shared resources among partitions (I/O, memory, ...)
- MMU may be a weak point -> solution by using one partition per LRU!

Fault Isolation



TTTech: System Partitioning using TDMA and other TTP mechanisms

- No control error propagation to other LRUs after (single) HW or SW fault
- Prevention of timing violations of controller by bus guardian
- Conflict-free use of communication resource among LRUs
- Communication system operates autonomously, based on predefined schedule, distributed network management and fault-tolerant time base

Benefits (I)

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Reduced (re)design costs

- Simplified design of complex integrated systems
- Reduced upgrade/extension/reconfiguration costs

Reduced integration and system testing costs

- integration provided per default
- no jitters, hazards, coupled temporal/logical effects and fault propagation
- concurrent engineering and separate testing possible!

Simplified design for system autonomy

- Improved stability as a result of strict control of key interfaces and system partitioning
- Simplified design of redundant systems and graceful degradation due to the built-in services

Benefits (II)

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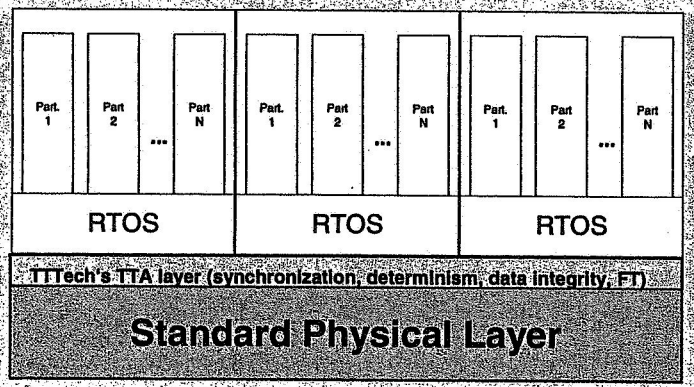
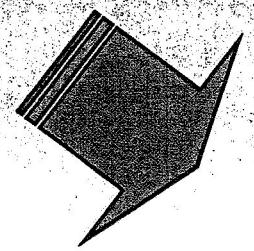
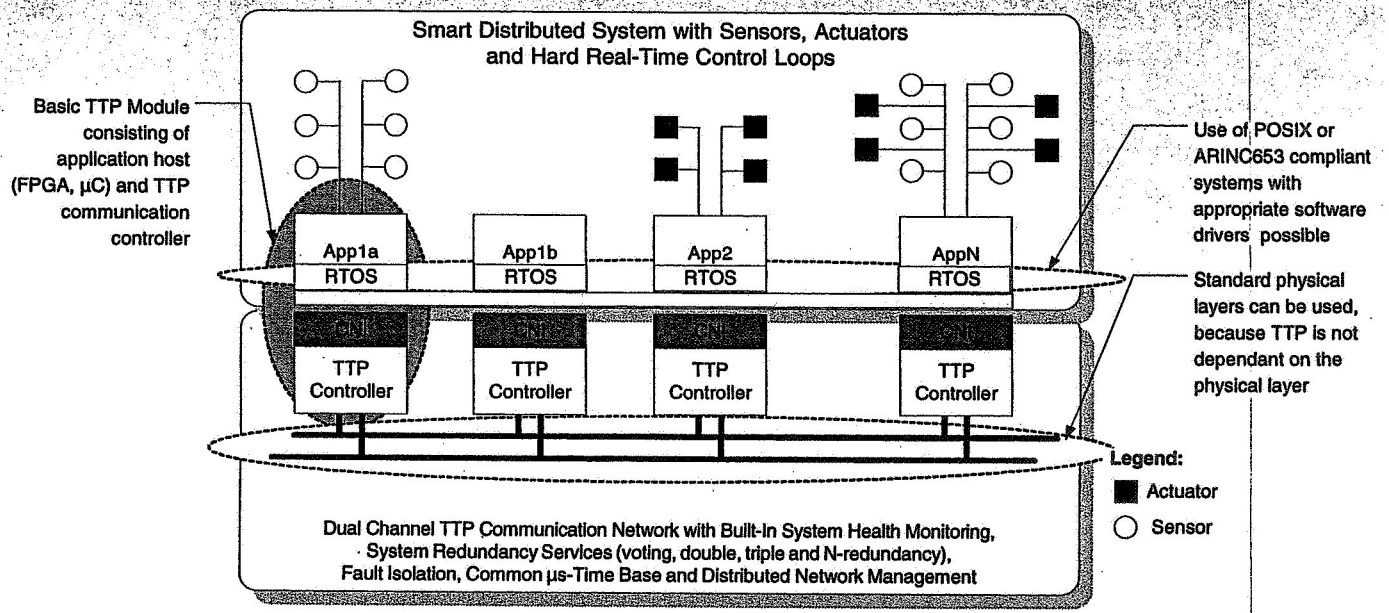
Reduced obsolescence management costs

- Application software can be made independent of:
  - OS version (e.g. 2.0 vs. 4.0)
  - Host hardware
  - system redundancy scheme
  - Physical layer / communication speed
- TTP as a thin layer between standard components







C2NF – TTTech's Chip IP for TTP Control

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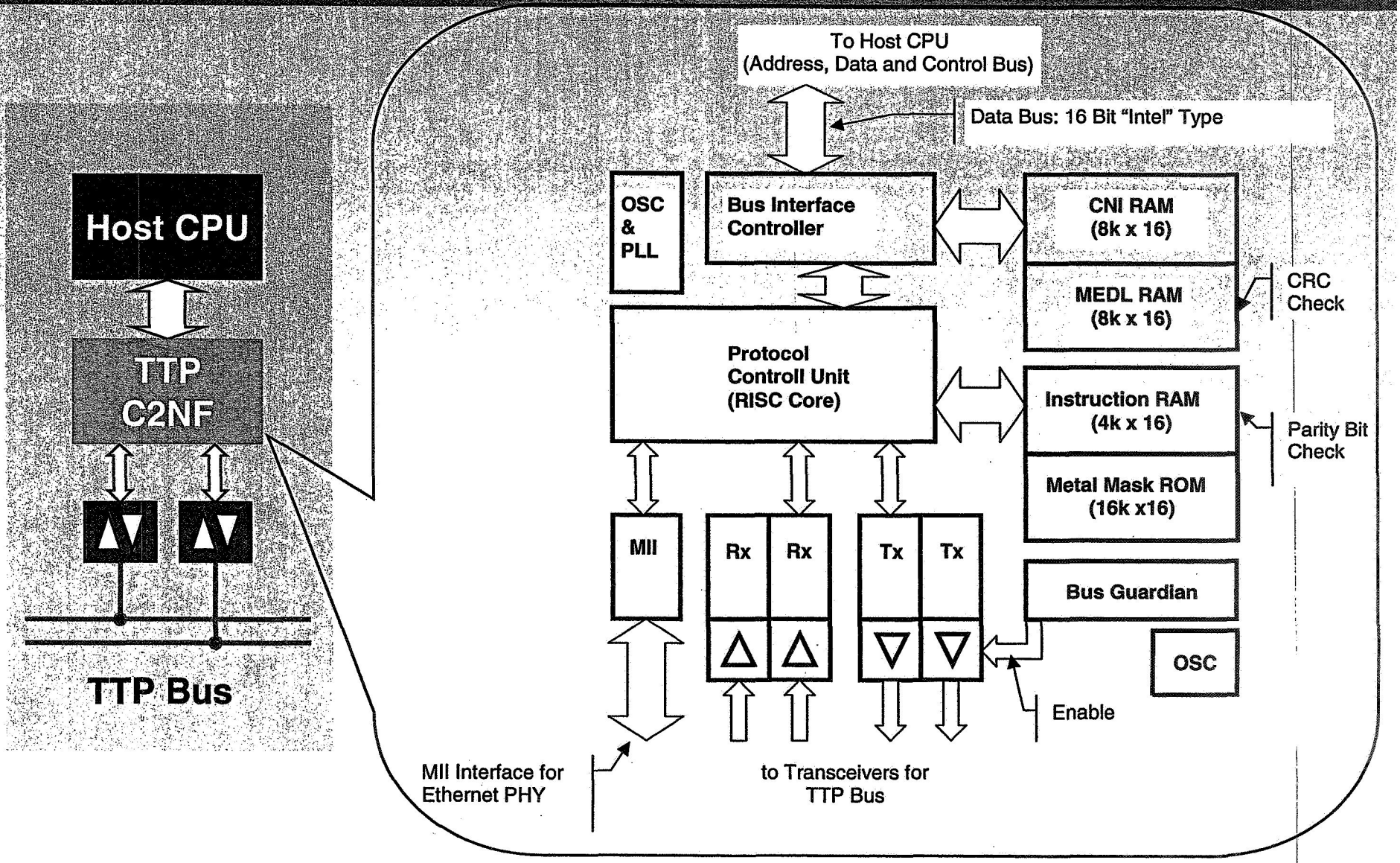

C2NF = TTP Controller with Processor Unit Core

- Fulfills TTP Protocol Specification
- Proprietary processor unit (RISC)
- TTP data transmission using MFM and Manchester coding
- MII interface for high speed Physical Layer
- 16 bit non-multiplexed host CPU interface
- 16k x 16 instruction ROM
- 16k x 16 MEDL and CNI SRAM
- 4k x 16 instruction SRAM

Notes:

MEDL = Message Descriptor List ; configuration register

CNI = Controller Network Interface ; dual ported RAM

Project: Space application

- Available standard controllers (e.g. AS8202NF by austriamicrosystems) are not qualified for space use
- C2NF implementation must be radiation tolerant
- Selected FPGA family RTAX 2000 (Actel)
- Major issues: limited RAM size, no PLLs

Study

- Evaluate required restrictions to original C2NF model
- Preliminary assumption: reduction of message buffer is necessary
- Evaluate impact to development tools and TTP network performance
- Target prototype with AX2000 devices (considering RT impacts)

C2NF – Rad Hard Implementation

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TBD. – work in progress

Here FPGA implementation study results will be introduced if available at the time of the conference.

Future Outlook: Technology Development

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Today:

- Specification stable since 2002
- Chips available since 1998

Tomorrow:

- More communication speed
- Advanced distributed services
- Improved support for IVHM

Note: IVHM = Integrated Vehicle Health Management

Future Outlook: Industry Applications

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Today:

- Control systems for Boeing 787
- Control systems for Airbus A380
- Control systems for military aircraft (F-16, M-346)
- Control systems for DARPA Grand Challenge (Red Team)

Tomorrow:

- Design wins of new „more electric“ aircraft (commercial/military)
- Design wins of new unmanned systems (UAV/UUV/UGVs)
- Design wins of new space systems

Future Outlook: Space Application

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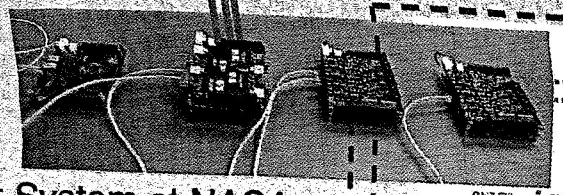

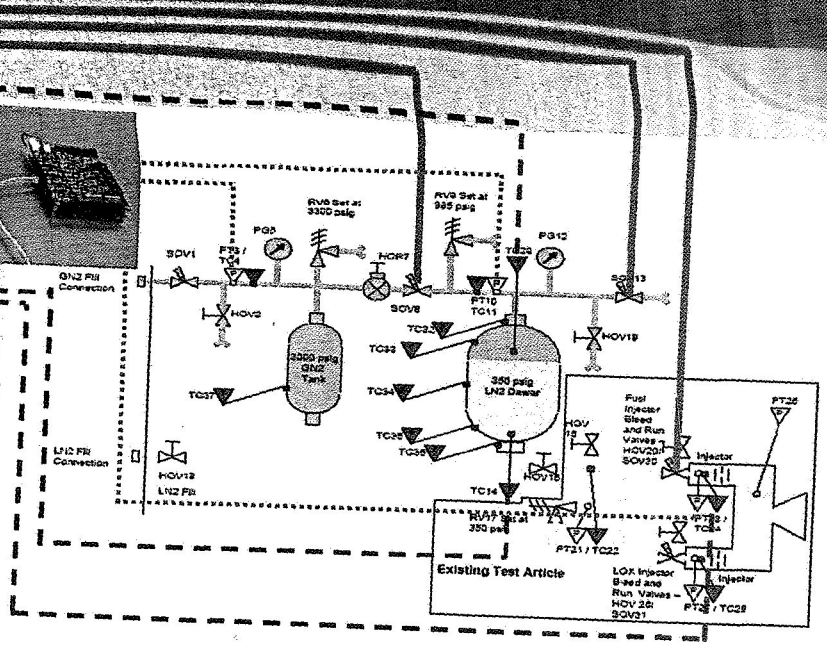

Today:

- Aerospace Development System at NASA MSFC
  - TTP is backbone of a modular distributed real time control system
  - Incorporates IEEE 1453.4 IEEE Standard for A Smart Transducer Interface for Sensors and Actuators—Mixed-Mode Communication Protocols and Transducer Electronic Data Sheet (TEDS) Formats
    - Plug-n-play sensors
  - Stackable function boards to tailor functionality at distributed modules
- Tested as controller for simulated pressure fed rocket engine – prototype for methane/lOX engine

Future:

- Continued refinement of development system for space applications through partnerships with Johnson Space Center and Kennedy Space Center
- Candidate for use in control of critical subsystems in future launch vehicles and manned spacecraft
- Candidate for Test Stand Operation – i.e. Methane/LOX engine hotfire testing at MSFC
- Candidate for Lunar missions – robotic and control of subsystems for lunar base infrastructure